Unit #6
Chemical Bonds / Stoicheometry / Nomenclature
Instructor's notes

Introduction

1) **Chemical bond -** A strong attractive force between atoms or ions in a molecule. They can be either ionic or covalent.

   a) **Ionic bond -** A chemical bond formed by the electrostatic attraction between oppositely charged ions. Simply stated: it results from the transfer of electrons.
      i) Examples: NaCl, KBr, $CaCl_2$, Fe_2O_3

   b) **Covalent bond -** Chemical bond formed by the sharing of electrons.
      i) Examples: H_2O, CO_2, $C_6H_{12}O_6$, CH_3OH
      ii) Remember: the single, double, and triple bonds drawn in unit #5. They were all covalent bonds.
      iii) Covalent bonds may be either of two types.
         (1) **Polar covalent -** A bond between two different atoms caused by the unequal sharing of the bonding electrons.
         (2) **Non-Polar covalent -** A bond between two atoms caused by the "equal" sharing of the bonding electrons.

2) Chemical bonds can occur between:

   a) Metal : Non-metal (Ionic) Examples: KI, MoS_2

   b) Non-metal : Non-metal (Covalent) Examples: O_2, N_2O

   c) Metals ≠ DO NOT bond with metals. **What can metals do with other metals?** *Answer: They can form mixtures more commonly called alloys.*

d) Remember from unit 2 that all elements can be classified into one of three different groups. **What are the three different groups?** *Answer: Metals, Metalloids, and Non-metals.* These can be determined by their position on the periodic chart.

   i) Metals: Anything to the left of the "stairs" on the periodic chart; except for Germanium (Ge), and Antimony (Sb).

   ii) Metalloid: Anything touching the "stairs" on the periodic chart, except for Aluminum (Al), Polonium (Po).

   iii) Non-metal: Anything to the right of the "stairs" on the periodic chart that is not touching the stairs.

3) **Electronegativity -** The measure of the attraction an atom has for shared electrons. (How much an atom wants electrons.)

   a) Excluding group 8 elements; the top, right corner is the most electronegative.
      i) Within a group / family: the closer to the top, the more electronegative.
      ii) Within a period / series: the further to the right, the more electronegative.

   b) Use the electronegativity in determining what type of chemical bond will form. (You will first have to calculate the difference in electronegativity. These values are on the back of your periodic chart, as well as in various chemistry texts.)
      i) If the difference is 1.6 or greater; the bond will be ionic.
      ii) If the difference is less than 1.6, and 0.4 or greater; the bond will be polar covalent.
      iii) If the difference is less than 0.4; the bond will be non-polar covalent.
      iv) The difference is determined by subtracting the smaller number from the larger.
      v) The element with the larger electronegativity will tend to have possession (hog) of the shared electrons more than the other element.

c) Examples:

i) NaCl

Na	=	0.93	
Cl	=	3.16	
		2.23	= ionic bond

ii) CO_2

C	=	2.55	
O	=	3.44	
		0.89	= polar covalent bond

iii) Cl_2

Cl	=	3.16	
Cl	=	3.16	
		0.00	= non-polar covalent bond

Ionic bonding

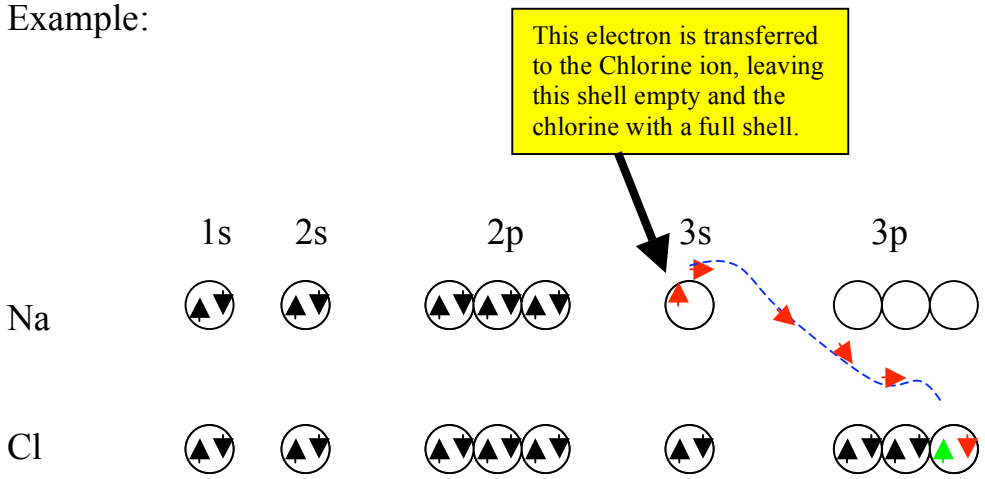
4) Remember definition of an ionic bond. **What is an ionic bond?**
Answer: A chemical bond formed by the electrostatic attraction between oppositely charged ions. Simply stated: it results from the transfer of electrons.
When do ionic bonds occur? *Answer: Metal bonds with a non-metal or when the difference in electronegativity is 1.6 or greater.*

5) **Ionic compound -** a compound composed of positive and negative ions. It is always written with the cation first, the anion second.
   a) Ionic compounds dissolve in polar solvents.

6) **Polyatomic ion -** an ion composed of 2 or more atoms. The charge is assumed to be on the entire molecule.
   a) Example: CO_3^{-2} (carbonate) has the -2 charge dispersed over the entire molecule.

7) **Ionic bonding -** Occurs when electrons are actually transferred from the outer shell (the valence shell) of one atom or molecule to the outer shell (the valence shell) of another, oppositely charged, atom or molecule.
   As a result both atoms usually attain filled valence shells with noble-gas configurations.
   This process of electron transfer is always exothermic.

Example:



$1\ Na^{+} + 1\ Cl^{-} \rightarrow\rightarrow\rightarrow 1\ NaCl$

1 Sodium ion + 1 Chlorine ion yields 1 Sodium chloride molecule (an ionic compound).

8) Properties of ionic compounds:
   Most are:

   a) Crystalline solids (crystal: molecules, atoms, ions are arranged in a 3-dimensional repeating pattern.)

   b) Very high melting points and even higher boiling points.
      i) Example: NaCl melts at 801^0C, boils at 1413^0C. Compare to covalent compounds (polar) NH_3: melts at -77.7^0C, boils at -33^0C; (non-polar) O_2: melts at -218.4^0C, boils at -182.96^0C.

   c) Dissolve in polar solvents (Ex: water)

   d) Conduct electric current when:
      i) In a molten state.
      ii) Dissolved in polar solvents (Ex: water).

9) Recall the difference between metals and non-metals:

a) **Where are the metals located on the periodic chart?** *Answer: left of the stairs; but not touching the stairs (exceptions: Al & Po are metals)*

b) **Where are the non-metals located?** *Answer: anything that is not a metal (see above) is a non-metal.*

c) Considering the number of valence electrons an atom has, **When does an atom gain or give electron(s)?** *Answer: They do which ever is easiest in order to achieve an octet of valence electrons.*

d) **If an atom "gives" away electrons, what happens to its oxidation state (charge) and what does it become?** *Answer: it gets more positive and becomes a cation.*

e) **If an atom "gains" electrons, what happens to its oxidation state (charge) and what does it become?** *Answer: it gets more negative and becomes an anion.*

f) Examples:
   i) Ca
      How many valence electrons does it have? *Answer: 2*
      Does it gain or give electrons? *Answer: Gives*
      How many does it give? *Answer: 2*
   ii) F
      How many valence electrons does it have? *Answer: 7*
      Does it gain or give electrons? *Answer: Gains*
      How many does it gain? *Answer: 1*

   iii) This will lead to the next section: "Stoicheometry". **Does anyone think they can "balance" the above example and get the correct formula?** *Answer: (If anyone is capable)* CaF_2 .

10) **Stoicheometry -** (1) balancing the charges on ions that are forming a molecule so that they add up to zero. (2) balancing chemical equation so the number of particles of reactants is equal to the number of particles of products. In this unit we will concern ourselves with the first definition.

a) The total electrons gained must equal the number lost.

b) Steps to "balancing" an ionic compound.
   i) Write the cation and the anion next to each other, leave some space between them.
   ii) Write the absolute value of the cation's charge as the subscript to the anion. (If this value is "1", you don't have to write anything.)
   iii) Write the absolute value of the anion's charge as the subscript to the cation. (If this value is "1", you don't have to write anything.)
   iv) Write the above determined subscripts in lowest terms.

c) Example 1: Write the balanced formula formed by combining the following ions: Ca^{+2} & Cl^{-1}
   i) Write the cation and the anion next to each other, leave some space between them.
   Ca^{+2} Cl^{-1}
   ii) Write the absolute value of the cation's charge as the subscript to the anion. (If this value is "1", you don't have to write anything.)
   Ca Cl_2
   iii) Write the absolute value of the anion's charge as the subscript to the cation. (If this value is "1", you don't have to write anything.)
   See "step ii)" above (we combined these two steps).
   iv) Write the above determined subscripts in lowest terms.
   $CaCl_2$

d) Example 2: Write the balanced formula formed by combining the following ions: Al^{+3} & O^{-2}
   i) Write the cation and the anion next to each other, leave some space between them.
   Al^{+3} O^{-2}
   ii) Write the absolute value of the cation's charge as the subscript to the anion. (If this value is "1", you don't have to write anything.)
   Al_2 O_3

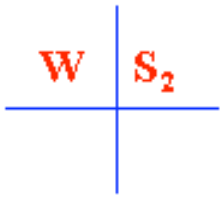
iii) Write the absolute value of the anion's charge as the subscript to the cation. (If this value is "1", you don't have to write anything.)
See "step ii)" above (we combined these two steps).
iv) Write the above determined subscripts in lowest terms.
Al_2O_3

e) Example 3: Write the balanced formula formed by combining the following ions: Mo^{+6} & O^{-2}
i) Write the cation and the anion next to each other, leave some space between them.
Mo^{+6} O^{-2}
ii) Write the absolute value of the cation's charge as the subscript to the anion. (If this value is "1", you don't have to write anything.)
Mo_2 O_6
iii) Write the absolute value of the anion's charge as the subscript to the cation. (If this value is "1", you don't have to write anything.)
See "step ii)" above (we combined these two steps).
iv) Write the above determined subscripts in lowest terms.
MoO_3

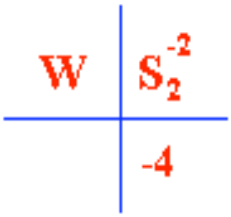
f) Sometimes, you may have a formula and you will need to determine the charge on the cation (this occurs when naming transition element compounds). Follow the steps presented below to achieve this goal:
i) STEP 1:
Write the formula, and separate the cation and anion with a cross.
ii) STEP 2:
Multiply the charge of the anion with the subscript of the anion (this will always be a negative number); and write this number in the lower right corner of the cross.
iii) STEP 3:
Write the absolute value of the number calculated above (in step 2) in the lower left corner of the cross.
iv) STEP 4:
Divide the number calculated in step 3 above by the subscript of the cation. This calculated value is the charge of the cation.

g) Example: WS_2

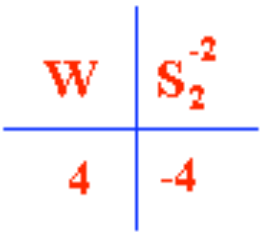
i) STEP 1:
Write the formula, and separate the cation and anion with a cross.



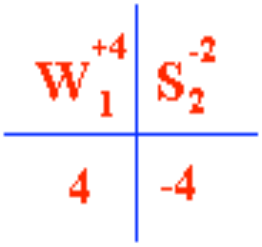
ii) STEP 2:
Multiply the charge of the anion with the subscript of the anion (this will always be a negative number); and write this number in the lower right corner of the cross.



iii) STEP 3:
Write the absolute value of the number calculated above (in step 2) in the lower left corner of the cross.



iv) STEP 4:
Divide the number calculated in step 3 above by the subscript of the cation. This calculated value is the charge of the cation.



11) **Nomenclature -** the naming of chemical compounds.

a) There are two general types of ionic compounds.
i) Those in which the cation has only one possible charge.
ii) Those in which the cation has more than one possible charge.
(1) Examples: Cations of transition elements. (Ti, Ru, Hg, U…)
(a) **Transition element -** elements that have "d" and "f" sub-levels. (See unit #3 if necessary to review "d & f sublevels").

b) These two types of ionic compounds require two different schemes to correctly name them.

c) If the cation has only one possible charge, name as follows:
i) Cation: Simply use the entire name of the element. (It will be capitalized).
ii) Anion: Use the entire name of the element; minus the ending, plus the suffix "-ide". (It will be lower case).
iii) If Polyatomic Cation or Anion: Use the whole name of the Polyatomic ion. Regardless if cation or anion.
iv) Examples:

(1) NaCl **Which element is the cation?** *Answer: Sodium.* **Does it have more than one possible oxidation state?** *Answer: No.* **How will we name it?** *Sodium.* **How will we name the anion?** *Answer: Drop the "-ine" ending from chlorine, and then add "-ide". This will be called chloride.* **What will we call the compound?** *Answer: Sodium chloride.*

(2) NH_4NO_3 **Which ion is the cation?** *Answer: Ammonium.* **Does it have more than one possible oxidation state?** *Answer: No.* **How will we name it?** *Ammonium.* **How will we name the anion?** *Answer: Since, it too is a polyatomic ion, we will simply use its entire name: nitrate* **What will we call the compound?** *Answer: Ammonium nitrate.*

d) If the cation has more than one possible charge, name as follows:
   i) Cation: Simply use the entire name of the element, followed by a roman numeral (in parenthesis) that indicates the charge of the cation. (It will be capitalized).
   ii) Anion: Same as the all other ionic compounds. (See "c, ii" & "c, iii" above.)
   iii) Examples:

(1) TiO_2 **Which ion is the cation?** *Answer: Titanium.* **Does it have more than one possible oxidation state?** *Answer: Yes.* **How will we name it?** *We will first have to determine its charge.* **(See section "9, e" of this unit if you forgot how to do this.)** *Once we have determined its charge we will call it "Titanium (IV)"* **How will we name the anion?** *Answer: Drop the "-ygen" ending from oxygen, and then add "-ide". This will be called oxide.* **What will we call the compound?** *Answer: Titanium (IV) oxide.*

(2) $Pb(OH)_4$ **Which ion is the cation?** *Answer: Lead.* **Does it have more than one possible oxidation state?** *Answer: Yes.* **How will we name it?** *We will first have to determine its charge.* **(See section "9, e" of this unit if you forgot how to do this.)** *Once we have determined its charge we will call it "Lead (IV)"* **How will we name the anion?** *Answer: Since, it too is a polyatomic ion, we will simply use its entire name: hydroxide.* **What will we call the compound?** *Answer: Lead (IV) hydroxide.*

Covalent bonding

12) Remember definition of a covalent bond. **What is a covalent bond?** *Answer*: Chemical bond formed by the sharing of electrons.

When do covalent bonds occur? *Answer: When a non-metal bonds with a non-metal or when the difference in electronegativity is less than 1.6.*

(Remember: a metal will never bond with another metal).

13) **Covalent molecule -** a molecule formed by 2 or more atoms sharing electrons to achieve an octet in their valence shells.

14) **Covalent bonding -** Occurs when electrons are shared from the outer shell (the valence shell) of one atom with the outer shell (the valence shell) of another. As a result both atoms attain filled valence shells with noble-gas configurations.

a) Remember: **What are the two types of covalent bonds?** *Answer: Covalent bonds may be either of two types.*

Polar covalent - A bond between two different atoms caused by the unequal sharing of the bonding electrons. If the difference is less than 1.6, and 0.4 or greater; the bond will be polar covalent.

Non-Polar covalent - A bond between two atoms caused by the "equal" sharing of the bonding electrons. If the difference is less than 0.4 ; the bond will be non-polar covalent.

b) During covalent bonding: all atoms need electrons. None of them gain or give electrons, they all share.

c) **Single bond -** created by the sharing of 1 pair of electrons. It is the weakest and longest of covalent bonds.

d) **Double bond -** created by the sharing of 2 pairs of electrons. It is stronger and shorter than a single covalent bond, but weaker and longer than a triple covalent bond.

e) **Triple bond -** created by the sharing of 3 pair of electrons. It is the strongest and shortest of covalent bonds.

f) Bond strength can be remembered with this analogy:

A truck is stuck in a snow bank. Upon seeing this, a passer-by offers to pull the stuck truck out of the snow bank. During the first attempt to pull the truck, the tow rope breaks at the very end (it was quite long and single stranded). The good Samaritan then takes his rope and doubles strands it (it is now half as long, but twice as strong); again it breaks at the end. On the final attempt, the rope was tripled (it is now one third its original length, but three times as strong); this time the stuck truck is freed from the bank.

You can think of covalent bond length and strength like that of the tow rope: longer (single strand) is weaker, shorter (triple strand) is stronger.

15) Properties of covalent compounds:

a) Non-metallic (O_2 and H_2O are covalently bonded)

b) Low melting and boiling points:
   i) Example: Ionic compound NaCl melts at 801^0C, boils at 1413^0C. Compare to covalent compounds (polar) NH_3: melts at -77.7^0C, boils at -33^0C; (non-polar) O_2: melts at -218.4^0C, boils at -182.96^0C.

c) Poor to non conductors of electricity
   i) (Rubber and plastics are covalently bonded.)

d) Often gaseous, but may be solid, liquid, or gas.
   i) Solid: Rubber, SiO_2
   ii) Liquid: Water, Alcohols
   iii) Gas: Methane, CO_2, NH_3

16) Covalent Nomenclature:

a) Usually, the least electronegative element is written first.

i) Examples: CO_2, N_2O, SO_3

b) Prefixes are used to indicate the number of each atom.

i)	1 atom	=	Mono (except when referring to the first element; in this case you will not use a prefix.)
ii)	2 atoms	=	Di-
iii)	3 atoms	=	Tri-
iv)	4 atoms	=	Tetr-
v)	5 atoms	=	Pent-
vi)	6 atoms	=	Hex-
vii)	7 atoms	=	Hept-
viii)	8 atoms	=	Oct-
ix)	9 atoms	=	Non-
x)	10 atoms	=	Dec-

c) The first element will be named by using the prefix (indicating the number of atoms) + the elements name.

i) Example: N_2O_4 = Dinitrogen

d) The second element will be named by using the prefix (indicating the number of atoms) + [element's name, - ending, + ide.]

i) Example: N_2O_4 = tetroxide

ii) **What is the complete name of N_2O_4?** *Answer: Dinitrogen tetroxide.*

17) A nomenclature flowchart follows this page. You will be given one in class, and you will be expected to be able to name various compounds **without** using the flowchart. (Memorize the "rules" for nomenclature.)

COMPOUND NAMING FLOWCHART

(NOTE: THIS CHART DOES NOT NAME BINARY ACIDS or TERNARY ACIDS)